

*XXXVII. The Report of the Committee appointed by the Royal Society to consider of the best Method of adjusting the fixed Points of Thermometers; and of the precautions necessary to be used in making Experiments with those Instruments.*

Read June 19, and Dec. 28, 1777.

I t is universally agreed by all those who make and use FAHRENHEIT's thermometers, that the freezing point, or that point which the thermometer stands at when surrounded by ice or snow beginning to melt, is to be called  $32^{\circ}$ ; and that the heat of boiling water is to be called  $212^{\circ}$ : but for want of further regulations concerning the manner in which this last point is to be adjusted, it is placed not less than two or three degrees higher on some thermometers, even of those made by our best artists, than on others. The two principal causes of this difference are, first, that it has never been settled at what height of the barometer this point is to be adjusted<sup>(a)</sup>; and

(a) FAHRENHEIT found that the heat of boiling water differed according to the height of the barometer; but supposed the difference to be much greater than

and secondly, that so much of the quicksilver in the thermometer as is contained in the tube, is more heated in the method used by some persons, than in that used by others. To shew that this last circumstance ought by no means to be disregarded, suppose that the ball of a thermometer be dipped into boiling water as far as to the freezing point, and consequently that the length of the column of quicksilver in that part of the tube which is not immersed in the water be  $180^{\circ}$ ; and suppose that the heat of that part of the column of quicksilver be no more than  $112^{\circ}$ . If the thermometer be now intirely immersed in the water, the heat of this column will be increased  $100^{\circ}$ ; and consequently its length will be increased by  $\frac{100}{11500}$  parts of the whole, as quicksilver expands  $\frac{1}{11500}$  part of its bulk by each degree of heat; and consequently the thermometer will stand  $\frac{180 \times 100}{11500}$  or rather more than  $1\frac{1}{2}^{\circ}$  higher than it did before.

Another thing to be considered in adjusting the boiling point is, that if the ball be immersed deep in the water, it will be surrounded by water which will be com-

than it really is. Mr. DE LUC has since, by a great number of experiments made at very different heights above the level of the sea, found a rule by which the difference in the boiling point, answering to different heights of the barometer, is determined with great exactness. According to this rule the alteration of the boiling point by the variation of the barometer from  $29\frac{1}{2}$  to  $30\frac{1}{2}$  inches is  $1^{\circ}.59$  of FAHRENHEIT.

pressed by more than the weight of the atmosphere, and on that account will be rather hotter than it ought to be.

We are of opinion, that the quicksilver in the tube ought, if possible, to be kept of the same heat as that in the ball, and that the ball ought not to be immersed deep in the water. These two requisites may be obtained by using a vessel covered so as to allow no more passage than what is sufficient for carrying off the steam; for then, if the thermometer be inclosed in this vessel in such manner that the boiling point shall rise but a little way above the cover, almost all the quicksilver in the tube will be surrounded by the steam of the boiling water, and consequently will be nearly of the same heat as the water itself: we therefore made some experiments to determine how regular the boiling point would be when tried in such vessels, both when the ball was immersed in the water, and when it was exposed only to the steam as recommended by Mr. CAVENDISH<sup>(b)</sup>

The vessel used in these experiments is represented in fig. 1. *Abba* is the pot containing the boiling water; *dd* is the cover; *E* is a chimney for carrying off the steam; *mm* is the thermometer fastened to a brass frame; this thermometer is passed through a hole *ff* in the cover, and rests thereon by a circular brass plate *gg* fastened

(b) Phil. Trans. vol. LXVI. p. 380.

to its frame, a piece of woollen cloth being placed between  $Gg$  and the cover, the better to prevent the escape of the vapours.

There were two pots of this kind used by us; one five inches in diameter and nine deep; the other,  $4\frac{1}{4}$  in diameter and 23 deep. Two of the thermometers principally used were the short ones, the brass plate ( $Gg$ ) being placed only  $3\frac{3}{4}$  inches above the top of the ball, and the boiling point rising not much above that plate: the third thermometer was much longer, the plate ( $Gg$ ) being 17 inches above the ball. They were all three quick; the first containing only  $2\frac{1}{2}$  degrees to an inch; the second  $5^{\circ}$ ; and the third  $10^{\circ}$ . The first had a cylinder instead of a ball  $1\frac{1}{2}$  inch long and  $\frac{4}{15}$  in diameter<sup>(c)</sup>; the two others had spherical balls, about  $\frac{3}{4}$  of an inch in diameter.

On trying these thermometers in the above mentioned vessels, with the water rising two or three inches above the top of the ball, we found some variations in the height according to the different manner of making the experiment, but not very considerable; for the most part there was very little difference whether the water boiled

(c) In the two short thermometers the quicksilver would have descended into the ball when cold, had not the tube been swelled a little, close to the ball, in order to prevent it.

fast or very gently; and what difference there was, was not always the same way, as the thermometer sometimes stood higher when the water boiled fast, and sometimes lower. The difference, however, seldom amounted to more than  $\frac{1}{10}$ th of a degree, unless a considerable part of the sides of the pot were exposed to the fire; but in some trials which we made with the short thermometers in the short pot, with near four inches of the side of the vessel exposed to the fire<sup>(d)</sup>, they constantly stood lower when the water boiled fast than when slow, and the height was in general greater than when only the bottom of the pot was exposed to the fire. This difference however was not perceived in the trials of the long thermometer in the deep pot, as there seemed very little difference in the height whether the water boiled fast or slow, or whether more or less of the side of the pot was exposed to the fire. The greatest difference observed in the same thermometer, on the same day and in the same water, according to the different manner of trying the experiment, was half a degree.

(d) In all our experiments, the water was boiled over a portable black-lead furnace, covered with an iron plate, which had a hole cut in it just big enough to receive the bottom of the pot; so that, by passing the bottom through this hole to a greater or less depth, we could expose more or less of the sides to the fire. In the other experiments, not more than one inch of the sides was ever exposed to the fire.

We

We made some trials with the long thermometer in the deep pot, to determine how much the height of the boiling point was affected by a greater or less depth of water above the ball. By a mean of the experiments it stood ,66 of a degree higher when the water rose 15 inches above the ball, than when it was only three inches above the ball; so that increasing the depth of water above the ball by 11 inches, raised the thermometer ,66 of a degree, that is ,06 for each inch.

We would by no means infer however from hence, that it is a constant rule, that the height of the boiling point is increased ,06 of a degree by the addition of each inch in the depth of the water above the ball; as perhaps the proportion would be found very different in greater depths of water or in wider vessels.

If this rule is constant, it would shew that, when the pressure on that part of the water which surrounds the ball is increased by increasing the depth of water above the ball, the height of the boiling point is not altered thereby more than half as much as by an equal increase of pressure produced by an alteration in the weight of the atmosphere: for the pressure on that part of the water which surrounds the ball is as much increased by an alteration of 11 inches in the depth of the water above the ball, as by an increase of  $\frac{11}{13\frac{1}{2}}$  of an inch in the height

of

of the barometer; and such an alteration in the height of the barometer is sufficient to raise the boiling point  $1^{\circ}, 3.$ .

It seems as if the height of the boiling point was in some measure increased by having a great depth of water below the ball, as in general the short thermometers stood higher when tried in the deep pot than in the short one; this effect, however, did not always take place. In the former of these cases, the depth of water below the ball was about 18 inches, in the other only 4; but the depth of water above the ball was the same in both cases.

It must be observed, that when there was a great depth of water in the vessel, either above or below the ball, the experiments were much more irregular, and the quicksilver in the tube remained much less steady than when it was small. When the depth of water in the vessel is great, it is apt to boil in gusts, which seems to be the cause of this irregularity; though we could not perceive any regular connection between these gusts and the rising of the thermometer.

In the experiments made with the water not rising so high as the ball, so that the thermometer was exposed only to the steam, we very seldom found any sensible difference whether the water boiled fast or slow: but whenever

whenever there was any, the greater height was when the water boiled fast; the difference, however, never amounted to more than  $\frac{1}{20}$ th of a degree.

There was scarce ever any sensible difference whether the short thermometers were tried in the short pot or the deep one, though in the former case the ball was raised very little above the surface of the water, and in the latter not less than 14 inches: neither did we find any sensible difference in trying them in the tall pot, whether there was a greater or less depth of water in the vessel.

As it was nevertheless suspected, that the heat of the steam might possibly be less near the top of the pot than lower down (for in these experiments the ball of the thermometer was always at the same depth below the cover, though its height above the surface of the water was very different) we made two holes in the side of a pot four inches deeper than the deepest of the foregoing, one near the top of the pot, and the other not far from the bottom, and passed the ball of the thermometer through one or the other of these holes, taking care to stop up both holes very carefully, so that no air could enter into the pot by them: no sensible difference could be perceived in the height, whether the thermometer was placed in the upper or lower hole, though in one

case the ball was only three inches, and in the other 21 inches, below the cover.

The heat of the steam therefore appears to be not sensibly different in different parts of the same pot; neither does there appear to be any sensible difference in its heat, whether the water boil fast or slow; whether there be a greater or less depth of water in the pot; or whether there be a greater or less distance between the surface of the water and the top of the pot; so that the height of a thermometer tried in steam, in vessels properly closed, seems to be scarce sensibly affected by the different manner of trying the experiment.

Though, as was before said, there was scarce any difference in the height of the quicksilver, whether the water boiled fast or slow, yet, when the water boiled slow, the thermometer was a great while before it rose to its proper height; and when it boiled very slow, it seemed doubtful whether it would have ever risen to it, especially if the ball was raised a great way above the surface of the water: but when, by making the water boil briskly, the thermometer had once risen to its proper height, the water might then be suffered to boil very gently, even for a great length of time, without the thermometer sinking sensibly lower<sup>(e)</sup>.

All

(e) The reason of this seems to be that, while any air is left in the pot, the steam

All three thermometers were found to stand, in general, from 30 to 65 hundredths of a degree higher when the ball was immersed a little way in the water (neglecting those observations in which much of the sides of the pot were exposed to the fire) than when it was tried in steam: at a medium they stood  $\frac{48}{100}$  higher, which is equal to the difference produced by a variation of  $\frac{3}{10}$ ths of an inch in the barometer; so that the boiling point, adjusted at a given height of the barometer, with the ball immersed a little way in the water, will in general agree with that adjusted in steam, when the barometer is  $\frac{3}{10}$ ths of an inch higher.

It must be observed, that in all these experiments a piece of flat tin plate was laid loosely on the mouth of the chimney E, so as to leave no more passage for the steam than what was sufficient to prevent the tin plate from being lifted up. In trying the thermometers in steam, this is by no means unnecessary; for, if the cover of the pot does not fit pretty close, the thermometers will immediately sink several degrees on removing the tin plate; but, when their balls are immersed in the water, the removal of the tin plate has no sensible effect.

steam cannot acquire its full degree of heat; and that when the water boils very gently, the air is not easily intirely expelled from the pot. That the steam will not acquire its full degree of heat while any air is left in the pot will appear from the next paragraph but one.

If this cover to the chimney had been heavy, the included steam might have been so much compressed thereby, that the water and steam might have acquired a considerably greater heat than they ought to have done; but as this plate lay loose on the chimney, and as its weight was not greater than that of a column of quick-silver, whose base is equal to that of the mouth of the chimney, and whose altitude is  $\frac{1}{50}$ th of an inch, the excess of the compression of the included steam above that which it would suffer in an open vessel, could not be greater than that which would be caused by an increase of  $\frac{1}{50}$ th of an inch in the height of the barometer, which is too small to be worth taking notice of; for, if the excess of compression was greater than that, the tin plate must necessarily be lifted up so much as to afford a sufficient passage for the steam to escape fast enough, though urged by no greater force than that.

Though in the different trials of the same thermometer in steam, on the same day, and with the same water, so little difference was observed, according to the different manner of trying the experiment; yet there was a very sensible difference between the trials made on different days, even when reduced to the same height of the barometer, though the observations were always made either with rain or distilled water. The difference,

however, never amounted to more than a quarter of a degree, except in one thermometer, in which there were three observations out of eighteen which differed more than that; one of them differed so much as  $0.65^{\circ}$  from some of the rest. In the observations made with the ball immersed a little way in the water, there was a greater difference between the observations of different days, even neglecting those in which much of the sides of the pot were exposed to the fire. In two of the thermometers the different observations differed about  $\frac{35}{100}$  of a degree from each other; but in the other thermometer they varied  $\frac{8}{10}$ ths.

We do not at all know what this difference could be owing to, especially in the observations in steam. It could not proceed intirely from some unknown difference in the water; for, if it did, the difference between the different thermometers should have been always the same, which was not the case, though in general, on those days in which one thermometer stood high, the others did also, especially in the trials in steam. Moreover, as far as can be perceived from our experiments, there seems to be very little difference between different waters with respect to the heat which they acquire in boiling. We could not be sure that there was any difference between rain or distilled water and pump water, provided

the latter had boiled long: neither did any difference seem to arise from the water containing such substances as are disposed to part readily with their phlogiston; for, on trying the thermometers in the steam of distilled water, their height was not sensibly altered by pouring in a small quantity of a solution of liver of sulphur, or of iron filings imperfectly rusted. The thermometer, however, seemed to stand sensibly lower in pump water beginning to boil, than in the same water long boiled, but the difference scarcely exceeded  $\frac{1}{10}$ th or  $\frac{1}{5}$ th of a degree.

We made some experiments to determine the heat of water boiling in open vessels. In general, when the vessel was almost full, and the water boiled fast, and the ball of the thermometer was held from three-quarters to two or three inches under water, and also in that part of the vessel where the current of water ascended upwards, that is, in the hottest part of the water, its heat was not much different from that of the steam of water boiling in closed vessels, varying only from a quarter of a degree more than that, to as much less; but if the water boiled gently, its heat would frequently be half or three-quarters of a degree cooler than the steam. If the experiment was tried in the deep pot with such a quantity of water in it that the surface was at least 14 or 15 inches below the top of the pot, so that though the vessel was open,

open, yet the water was not much exposed to the air, its heat then seemed scarcely less than when boiled in closed vessels.

In making these experiments we chiefly made use of the two short thermometers, in which, as the quantity of quicksilver contained in the tube was small, the error arising from that part of the quicksilver being not heated equally with that in the ball, could be but small: for example, in the second of the short thermometers, the number of degrees contained in that part of the tube between the circular plate *Gg* and the ball was  $18^{\circ}$ . In the experiments in steam this part of the tube was heated to the same degree as the ball. Suppose now, that in open vessels it was heated only to  $122^{\circ}$ , or was  $90^{\circ}$  cooler than the ball, it is plain, that the thermometer would stand only  $\frac{18 \times 90}{11500}$ , or  $\frac{1}{7}$ th of a degree lower than it did in steam, provided the heat of the quicksilver in the ball was the same in both cases. In the other short thermometer, as there were only half as many degrees to an inch, the error was only half as great.

In several of the experiments, however, we made use of the long thermometer; but then it was necessary to make an allowance on account of the quicksilver in the tube being not heated equally with that in the ball. The better

better to enable us to do this, we made use of a thermometer tube, filled with quicksilver in the same manner as a thermometer, only without any ball to it, or a thermometer without a ball, as we may call it. A small brass plate was fixed to the tube near the top of the column of quicksilver, to shew the heat as in a common thermometer. In all our experiments with the long thermometer in open vessels, this tube without a ball, was placed by its side; whence, as the quicksilver in the tube of the long thermometer could hardly fail of being nearly of the same heat as that in the tube without a ball, we knew pretty nearly the heat of the quicksilver in the tube of the former, and consequently how much higher it would have stood if the quicksilver in its tube had been of the same heat as that in the ball. For example, on October 19, the long thermometer tried in an open vessel, the water boiling fast, stood  $1^{\circ}.65$  lower than it did when tried in steam the same day, the quicksilver in the tube without a ball standing at the same time at  $109^{\circ}$ : we may therefore conclude, that the heat of the quicksilver, in that part of the tube of the long thermometer which was not immersed in the water, was also  $109^{\circ}$ ; and consequently, as that part of the tube contained about  $170^{\circ}$ , the thermometer stood  $\frac{170 \times 103}{11500}$ , or

$1^{\circ}.52$  lower than it would have done if the quicksilver in the tube had been of the same heat as that in the ball; and, consequently, the quicksilver in the ball of the thermometer was in reality  $.07$  cooler than when tried in steam.

We examined the boiling points of several thermometers, made by different artists, by trying them in steam when the barometer was at  $30.1$ , and finding what division on the scale the quicksilver stood at. The difference of the extremes was  $3^{\circ}\frac{1}{4}$ ; but, by a mean of all, it was found to stand at  $213^{\circ}.1$ , and consequently would have stood at  $212^{\circ}$ , if the barometer had been at  $29.4$ ; so that if the boiling point was to be adjusted, either in steam, when the barometer is at  $29.4$ , or with the ball immersed two or three inches in water, when the barometer is at  $29.1$ , it would agree best with the mean of the abovementioned thermometers. But as it seems to be of no great signification to make the boiling point agree very nearly with the mean of the thermometers made at present, when the extremes differ so widely; and as we apprehend that it will be more convenient to the makers that some height should be chosen which differs less from the mean, as thereby they will more frequently have an opportunity of adjusting the boiling point without the trouble and danger of mistakes which attend the making

making a correction, we recommend, that the boiling point should be adjusted when the barometer is at 29.8, if the person chooses to do it in steam; or when the barometer is at 29 $\frac{1}{2}$ , if he chooses to do it in close vessels, with the ball immersed to a small depth under the water. Our reason for pitching upon this precise height is, that thereby the boiling point will differ from Mr. DE LUC's boiling point, by a simple fraction of the degrees of his common scale, namely three-quarters of a degree higher.

We are informed by Mr. DE LUC, that the method he used in adjusting the boiling point, though he forgot to mention it in the *Récherches sur les Modifications de l'Atmosphère*, was to wrap rags round the tube of the thermometer, and to try it with the ball immersed in water in an open vessel, of the form described in the above-mentioned book, while boiling water was poured at different times on the rags, in order that the quicksilver in the tube might be heated, if possible, to the same degree as that in the ball. As well as we can judge from the abovementioned experiments in open vessels, and from the few trials we have made of this method, we are inclined to think, that the boiling point adjusted this way will in general differ but little from that adjusted in steam at the same height of the barometer, especially if the thermometer be not very long, and do not extend a great way

way below the freezing point<sup>(f)</sup>; consequently, as Mr. DE LUC's boiling point was adjusted when the barometer was at 27 Paris or 28.75 English inches, it will stand lower than that adjusted in the manner recommended by us, by three-quarters of a degree of his scale; or  $80^{\circ}\frac{1}{4}$  on DE LUC's thermometer, will answer to  $212^{\circ}$  on FAHRENHEIT's adjusted in the manner proposed.

Though the boiling point be placed so much higher on some of the thermometers now made than on others, yet we would not have the reader think that this can make any considerable error in the observations of the weather, at least in this climate; for an error of  $1^{\circ}\frac{1}{2}$  in the position of the boiling point will make an error of only half a degree in the position of  $92^{\circ}$ , and of not more than a quarter of a degree in the point of  $62^{\circ}$ . It is only in nice experiments, or in trying the heat of hot liquors, that this error in the boiling point can be of much signification.

(f) In order to see how much the quicksilver in the tube of the thermometer would be heated in this method of adjusting the boiling point, we took the abovementioned tube without a ball, wrapped it round with rags, and poured boiling water on it as above described: the heat of the quicksilver therein was found to be about  $21^{\circ}$  less than that of boiling water; and, therefore, the boiling point of a thermometer, adjusted in this manner, supposing the thermometer to be dipped into the water as far as to the point of  $32^{\circ}$ , should stand about one-third of a degree lower than it would do if the quicksilver in the tube was heated equally with that in the ball.

There is another circumstance that we have not yet taken notice of, which, in strictness, causes some error in thermometers, namely, the difference of expansion of the glass tube and the scale. But this error is in almost all cases so small as to be not worth regarding; we have, however, in the note below given a rule for computing the value of it <sup>(g)</sup>.

(g) The usual way of adjusting thermometers is, to mark the boiling and freezing points on the glass tube, and not to set off those points on the scale till some time after, when the tube and scale may both be supposed to be nearly of the temper of the air in the room; consequently, when the thermometer is exposed to a greater heat than that, the scale, if of brass, will expand more than the glass tube, and the divisions on it will be longer than they ought to be; but, if the scale be of wood, it will expand less than the glass tube, and the divisions will be too short. Let now the heat of the air, when the divisions were set off on the scale, be called A; let the degree of heat which the thermometer stands at in the experiment be called D; and let the degree answering to that point of the scale in which the thermometer is fastened to the scale be called F. Then, if all parts of the thermometer and scale are heated equally, and the scale is of brass, the thermometer will appear to stand lower than it ought to do by the  $\frac{D-F \times D-A}{165000}$  part of a degree, observing, that if  $D-F \times D-A$  is negative, it will stand higher than it ought to do; but if the scale is of wood, it will stand higher than it ought to do by the  $\frac{D-F \times D-A}{216000}$  part of a degree.

If the thermometer be fastened to the scale by the ball, or any part of the tube lower than the observed heat, the error will be the same, whether that part of the tube and scale, which is above the observed degree, be of the same heat as the ball or not: but if the thermometer is fastened to the scale by the top of the tube, as is frequently done, then the error will vanish whenever that part of the tube and scale, which is above the observed degree, is not much heated. This rule is founded on Mr. SMEATON's experiments, who found, that white glass expands  $\frac{1}{80}$ th of an inch in a foot by  $180^{\circ}$  of heat; that brass wire expands  $\frac{1}{333}$ ; and that wood expands scarce sensibly.

In making experiments with thermometers, it evidently is equally necessary that the quicksilver in the tube should be of the same heat as that in the ball, as it is in adjusting the boiling point: for this reason, in trying the heat of liquors much hotter or colder than the air, the thermometer ought, if possible, to be immersed as far as to the top of the column of quicksilver in the tube. As this, however, would often be very difficult to execute, the observer will frequently be obliged to content himself with immersing it to a much less depth. But then as the quicksilver, in a great part of the tube, will be of a different heat from that in the ball, it will be necessary, where any degree of accuracy is required, to make a correction, on that account, to the heat shewn by the thermometer. If the heat of the quicksilver in the tube be known, the correction may readily be made by help of the annexed table; the only difficulty lies in estimating what that heat may be. In all probability the heat of the quicksilver in the tube will not be very different from that of the air which surrounds it<sup>(b)</sup>; but as that

(b) This must evidently be the case, unless the quicksilver in the tube is considerably heated by its contact with that in the ball. To see whether this was the case, some sand was heated in a small copper dish over a lamp to the heat of about  $212^{\circ}$ , and the abovementioned tube, without a ball, laid horizontal with the end extending about half an inch over the sand; but, to prevent its being heated thereby, a piece of wood, about a quarter of an inch thick,

that air will be affected by the steam of the liquor, and the fire by which it is heated, it will commonly be of a very different heat from the rest of the air of the room in which the experiment is made; but as no great nicety is required in estimating the heat of the quicksilver in the tube, insomuch that a mistake of  $25^{\circ}$  therein will cause an error of only half a degree in the correction, when the number of degrees in that part of the tube which is not immersed in the liquor is not more than  $220^{\circ}$ , it will commonly be not difficult to guess at the heat of the quicksilver in the tube as near as is required<sup>(i)</sup>. But if the observer is desirous of more accuracy,

was laid between the sand and it. After it had remained a sufficient time in this situation, the division which the quicksilver stood at was observed. The piece of wood was then removed, and the end of the tube laid in the sand, which was heaped over it so that about half an inch of the column of quicksilver was entirely surrounded by the hot sand, and must therefore be heated to nearly the same degree as it. The quicksilver in the tube rose very little higher than before, and seemingly not more than might be owing to the expansion of the half inch of quicksilver which was surrounded by the sand; so that it should seem, that heating one end of the column of quicksilver does not communicate much heat to the rest of the column; and consequently, that, when the ball of a thermometer is immersed in hot liquor, the quicksilver in the tube will not be much hotter than the surrounding air.

(i) The better to enable the reader to guess at the heat of the quicksilver in the tube, in cases of this kind, we tried how much the quicksilver in the above-mentioned tube, without a ball, would be heated when held over a vessel of boiling water. It is true, that these experiments cannot be of any great service towards this purpose, as the tubes will be very differently heated, according to the

racy, he may find the heat of the surrounding air by holding the ball of a small thermometer near the tube  
of

the degree of heat of the fluid, and the quantity of steam which it furnishes, and according to the nature of the fire by which it is heated; yet as the experiments may perhaps serve in some measure to rectify our ideas on this head, we will give the result. When the abovementioned tube without a ball \*, the length of the column of quicksilver in which was 15 inches, was held perpendicularly over the vessel of boiling water, with its bottom even with the surface of the water, the heat of the quicksilver was in all the trials we made from 68 to 28° hotter than the air of the room. If the tube was held inclined to the horizon, in an angle of about 30°, with the bottom of the column of quicksilver reaching not more than three quarters of an inch within the circumference of the pot, so that the column of quicksilver was as little heated by the steam as could easily be done, it was from 30 to 7° hotter than the air. When a shorter tube of the same kind, in which the column of quicksilver was seven inches, was used, the quicksilver was from 62 to 44° hotter than the air, when held perpendicularly, and from 49 to 36° hotter when held inclined. The water in these trials frequently boiled pretty fast, but never very violently. It was in general heated over a portable black lead furnace placed in the middle of the room; but it was once heated over an ordinary chafing-dish, when the quicksilver in the long tube, held perpendicularly, was found to be 64° hotter than the air. When the experiments were tried without doors, the heat of the quicksilver in the tube would vary very much, according as the wind blew the steam and hot air from or towards the tube, but it sometimes rose as high as it did within doors.

The most convenient method we know of making these tubes without a ball is, to fill a thermometer in the usual manner, and heat the ball till there is a proper quantity of quicksilver in the tube, and then to make the column of quicksilver separate at the neck of the ball, and run to the extremity of the tube, so as to leave a vacuum between the ball and the column of quicksilver, as is expressed in fig. 2. where the shaded part AD represents the column of quicksilver, and BA that part in which there is a vacuum. The tube must then be sealed some-

\* See p. 830. l. 1.

where

of the thermometer with which he tries the heat of the liquor; or, what will be much better, he may have a tube without a ball, such as is above described, fastened to the frame of the thermometer, on one side of the tube; or if he has two such tubes, of different lengths, it will be still more accurate.

To avoid the inconvenience of this correction, perhaps it may be thought, that both in adjusting the boiling point and in trying the heat of liquors, it would be better that not much more than the ball of the thermometer should be immersed, and that the tube should be held inclined in such manner as to be heated as little as possible; as it may be said, that by this means you will find the heat of liquors pretty nearly, without the trouble of making any correction; and that, though in strictness a correction would be required in observing the heat of the air with

where between  $B$  and  $A$  as at  $E$ , and cut off there; after which it must be held with the end  $D$  upwards, so as to make the column of quicksilver run to the extremity  $E$ : by this method of filling it is plain, that no sensible quantity of air can be left between  $E$  and the column of quicksilver; but yet the quicksilver will be apt not to run sufficiently close to the extremity  $E$ , as the weight of the column will be scarcely sufficient to force it into the narrow space which will commonly be left in sealing the tube, especially when held nearly horizontal: for this reason it will be proper to open the tube at  $D$ , so as to let in the air, and then seal it again. It must be observed, that the space left between  $D$  and the column of quicksilver ought not to be less than the tenth part of the length of the column of quicksilver, as otherwise the included air might be too much compressed by the expansion of the quicksilver when much heated.

such

such thermometers, yet the heat of the atmosphere never differs so much from the mean heat, as to make that correction of much consequence<sup>(k)</sup>. But, on the other hand, this method of making and using thermometers is much less exact than the former, and therefore is unfit for nice experiments; and, besides, a correction would be as necessary with this kind of thermometer in trying the heat of air, artificially heated, or in finding the heat of large quantities of hot liquors, in which it would be difficult to prevent the quicksilver in the tube from being heated

(k) The degrees on all thermometers are intended to answer to equal portions of the solid contents of the tube; and, consequently, if the quicksilver in the tube is kept constantly of the same heat as that in the ball, the degrees will answer to equal increments of bulk of the whole quantity of quicksilver in the thermometer, that is of a given weight of quicksilver. But if only the quicksilver in the ball is heated, and that in the tube is kept always of the same heat, the degrees will answer to equal increments of a given bulk of quicksilver; so that the scale of the thermometers will be really different in these two methods of proceeding, and in high degrees the difference will be very considerable: for example, let two thermometers be made, and in the first of them let care be taken, both in adjusting the fixed points and in trying the heat of liquors, that the quicksilver in the tube shall be of the same heat as that in the ball; and in adjusting the fixed points of the second, and in trying the heat of liquors with it, let care be taken that the quicksilver in the tube shall remain always of the same invariable heat, and let the freezing and boiling points be marked 32 and 212 on both of them: then will the degree of 620 on the first answer to that of 600 on the second; that of 406 to 400; that of 302 to 300; and that of 119.7 to 120; that is, a liquor which appears to be of 620° of heat by the first will appear to be of 600 by the second, &c. It appears from hence, that it would be improper to employ the latter method of adjusting and using thermometers for ordinary purposes, and the former for nice experiments.

by the steam, as it is in finding the heat of liquors with the other thermometer, whenever the ball is not immersed to a sufficient depth; so that, on the whole, the former method of making and using thermometers seems much the best.

A much better way of avoiding the trouble of making a correction would be to have two sets of divisions made to such thermometers as are intended for trying the heat of liquors; one of which should be used when the tube is immersed almost to the top of the column of quicksilver; and the other, when not much more than the ball is immersed, in which last case the observer should be careful that the tube should be as little heated by the steam of the liquor as conveniently can be. It is difficult to give rules for constructing this second set of divisions, as the heat of the quicksilver in the tube will be very different according to the temper of the air in the room, the quantity and nature of the fluid whose heat is to be tried, the manner in which it is heated, and the other circumstances of the experiment; but, on the whole, we think that, given in the following table, would be as proper as any.

Degree answering to that point of the tube which is two inches above the ball.							
	+ 75	+ 50	+ 25	0	- 50	- 100	- 200
- 500							
- 400							
- 300							
- 250							
- 200							
- 150							
- 100							
- 50							
0							
+ 50							
+ 100							
+ 150	149.5	149.4	149.	148.7	148.4	147.3	147.
+ 200	198.8	198.5	198.3	198.	197.5	197.	
+ 250	247.5	247.1	246.8	246.4	245.7		
+ 300	295.8	295.3	294.9	294.4	293.4		
+ 350	343.7	343.1	342.5	342.			
+ 400	391.1	390.4	389.7	389.1			
+ 450	438.1	437.3	436.5	435.7			
+ 500	484.7	483.8	482.9	482.			
+ 600	576.5	575.4	574.3	573.2			

To make use of this table, seek in the uppermost horizontal line the degree of the thermometer answering to that point of the tube which is two inches above the ball; and in the left-hand column seek the degrees of the second set of divisions; the corresponding numbers in the table are the corresponding degrees of the first set, or the degrees which they must be set opposite to. The right-hand perpendicular column shews the heat which the quicksilver in the tube was supposed to be of in forming this table.

Though this second set of divisions be far from accurate, yet it is at least as much so as a thermometer adjusted in the latter method can be; so that this double set of divisions possesses all the advantages which can be expected from that method of adjusting thermometers, without the inconveniences.

A table for correcting the observed height of a thermometer, whenever the quicksilver in the tube is not of the same heat as that in the ball.

Diff. of Heat	Degrees not immersed in the liquors.														
	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750
50	.2	.4	.7	.9	1.1	1.3	1.5	1.7	2.	2.2	2.4	2.6	2.8	3.1	3.3
100	.4	.9	1.3	1.8	2.2	2.6	3.0	3.5	3.9	4.4	4.8	5.2	5.7	6.1	6.6
150	.7	1.3	2.0	2.6	3.3	3.8	4.6	5.2	5.9	6.5	7.2	7.9	8.4	9.2	9.8
200	.9	1.8	2.6	3.5	4.4	5.1	6.1	7.0	7.8	8.7	9.6	10	11	12	13
250	1.1	2.2	3.3	4.4	5.5	6.4	7.6	8.7	9.8	11	12	13	14	15	16
300	1.3	2.6	3.8	5.1	6.4	7.7	9.1	10	12	13	14	16	17	18	20
350	1.5	3.0	4.6	6.1	7.6	9.1	11	12	14	15	17	18	20	21	23
400	1.7	3.5	5.2	7.0	8.7	10	12	14	16	17	19	21	23	24	26
450	2.	3.9	5.9	7.8	9.8	12	14	16	18	20	22	24	25	27	29
500	2.2	4.4	6.5	8.7	11	13	15	17	20	22	24	26	28	31	33
550	2.4	4.8	7.2	9.6	12	14	17	19	22	24	26	29	31	34	36

To make use of this table, in the left-hand perpendicular column look for the number of degrees contained in that part of the tube which is not immersed in the fluid whose heat is to be tried, and in the upper horizontal line seek the supposed difference of heat of the quicksilver in that part of the tube from that in the ball; the corresponding number in the table is the correction, which must be added to the observed heat when the

quicksilver in the tube is cooler than that in the ball, and subtracted when it is warmer: for example, let the observed heat of the fluid be  $475^\circ$ , let the thermometer be immersed in the fluid as far as to the degree of  $25^\circ$ , or to that part of the tube which should be marked  $25^\circ$  if the divisions were continued long enough; then is the number of degrees in that part of the tube which is not immersed in the fluid  $450$ ; and let the heat of the quicksilver in that part of the tube be supposed  $100^\circ$ ; and consequently, the difference of heat of the quicksilver in that part of the tube from that in the ball  $375$ ; then in the left-hand perpendicular column seek the number  $450$ , and in the upper horizontal line the number  $375$ ; the corresponding number in the table, or the correction, is  $15^\circ$ , and therefore the true heat of the fluid is  $490^\circ$ .

This correction may be had very easily without the help of the table, only by multiplying the number of degrees not immersed in the fluid by the supposed difference of heat, dividing the product by  $10000$ , and diminishing the quotient by one-eighth part of the whole.

In the following pages we have thrown together the practical rules, which we would recommend to be observed in adjusting the fixed points of thermometers.

*Rules to be observed in adjusting the boiling point.*

The most accurate way of adjusting the boiling point is, not to dip the thermometer into the water, but to expose it only to the steam, in a vessel closed up in the manner represented in fig. 4. where *Abba* is the vessel containing the boiling water, *dd* the cover, *E* a chimney made in the cover intended to carry off the steam, and *mm* the thermometer passed through a hole in the cover. Those who would make use of this method must take care to attend to the following particulars.

1st, The boling point must be adjusted when the barometer is at 29.8 inches; unless the operator is willing to correct the observed point in the manner directed below.

2dly, The ball of the thermometer must be placed at such a depth within the pot, that the boiling point shall rise very little above the cover; for otherwise part of the quicksilver in the tube will not be heated, and therefore the thermometer will not rise to its proper height. The furfase of the water in the pot also should be at least one or two inches below the bottom of the ball; as otherwise the water, when boiling fast, might be apt to touch the ball: but it does not signify how much lower than that the surface of the water may be.

3dly,

3dly, Care must be taken to stop up the hole in the cover through which the tube is inserted, and to make the cover fit pretty close, so that no air shall enter into the pot that way, and that not much steam may escape. A piece of thin flat tin plate must also be laid on the mouth of the chimney, so as to leave no more passage than what is sufficient to carry off the steam. The size of this plate should be not much more than sufficient to cover the chimney, that its weight may not be too great; and the mouth of the chimney should be made flat, that the plate may cover it more completely. It must be observed, that when the tin plate is laid on the mouth of the chimney, it will commonly be lifted up by the force of the steam, and will rattle till it has slipped aside sufficiently to let the steam escape without lifting it up. In this case it is not necessary to put the plate back again, unless by accident it has slipped aside more than usual. If the artist pleases, he may tie each corner of this plate by a string to prongs fixed to the chimney, and standing on a level with the plate, as thereby it will necessarily be kept always in its place<sup>(1)</sup>; but we would by no means recommend having it made with a hinge, as that might

(1) Fig. 3. is a perspective view of the chimney and tin plate; ABCD is the plate; E the chimney; Ff, Gg, Mm, and Nn, the prongs fastened to the chimney, to which the four corners of the plate are to be tied by the strings AF, BG, CM, and DN; the ends F, G, M, and N, of the prongs must be on a level with the plate, and the strings should not be stretched tight.

be apt to make it stick, in which case the included vapour might be so much compressed as to cause an error. We would also by no means advise lining the tin plate with leather, or any other soft substance, for the sake of making it shut closer, as that also might be apt to make it stick. The chimney also ought not to be made <sup>of</sup> less than half a square inch in area: for though a smaller chimney would be sufficient to carry off the steam, unless the vessel is much larger than what we used; yet the adhesion which is apt to take place between it and the tin plate when wet, might perhaps bear too great a proportion to the power which the included steam has to lift it off, if it was made much less. It is convenient that the chimney be not less than two or three inches long, as thereby the observer will be less incommoded by the steam; but it would be improper to make it much longer, for the longer the chimney is, the greater disposition has the air to enter into the pot between it and the cover.

It is most convenient not to make the cover fit on tight, but to take on and off easily; and to wrap some spun cotton round that part of the cover which enters into the pot, in order to make it shut closer; or, what seems to answer rather better, a ring of woollen cloth may be placed under the cover, so as to lie between the top

of

of the pot and it. These methods of making the cover shut close can be used more conveniently when the cover is made to enter within the pot, as in the figure, than when it goes on on the outside.

There are various easy ways by which the hole in the cover, through which the tube of the thermometer is passed, may be stopped up, and by which the thermometer may be suspended at the proper height. The hole in the cover may be stopped up by a cork, which must first have a hole bored through it, big enough to receive the tube, and be then cut into two, parallel to the length of the hole. Another method, more convenient in use, but not so easily made, is represented in fig. 6. which exhibits a perspective view of the apparatus; *A a* is the cover; *H* the hole through which the thermometer is passed; *B b* a flat piece of brass fixed upon the cover; and *D d E e* a sliding piece of brass, made so as either to cover the hole *H*, or to leave it uncovered as in the figure, and to be tightened in either position by the screw *s* sliding in the slit *M M*; a semi-circular notch being made in the edge *B b*, and also in the edge *D d*, to inclose the tube of the thermometer: pieces of woollen cloth should also be fastened to the edges *B b* and *D d*, and also to the bottom of the sliding piece *D d E e*, unless that piece and the cover are made sufficiently flat, to prevent the escape of the steam. In

order

order to keep the thermometer suspended at the proper height, a clip may be used like that represented in fig. 7. which by the screw *s* must be made to embrace the tube tightly, and may rest on the cover. That part of the clip which is intended to bear against the tube, had best be lined with woollen cloth, which will make it stick tighter to the tube, and with less danger of breaking it. Another method, which is rather more convenient, when the top of the tube of the thermometer is bent into a right angle, in the manner frequently practised at present for the sake of more conveniently fixing it to the scale, is represented in the same figure; *GgFf* is a plate of brass, standing perpendicularly on the cover, and *L/Nn* a piece of brass, bent at bottom into the form of a loop, with a notch in it, so as to receive the tube of the thermometer, and to suffer the bent part to rest on the bottom of the loop; this piece must slide in a slit *kk*, cut in the plate *L/Nn*, and be tightened at any height by the screw *t*.

4thly, It is best making the water boil pretty briskly, as otherwise the thermometer is apt to be a great while before it acquires its full heat, especially if the vessel is very deep. The observer too should wait at least one or two minutes after the thermometer appears to be stationary, before he concludes that it has acquired its full height,

5thly, Though, as was said before, this appears to be the most accurate way of adjusting the boiling point; yet, if the operator was to suffer the air to have any access to the inside of the vessel, he would be liable to a very great error: for this reason we strongly recommend it to all those who use this method, not to deviate at all from the rules laid down without assuring themselves, by repeated trials with a pretty sensible thermometer, that such alteration may be used with safety. But the covering the chimney with the tin plate ought by no means to be omitted; for though, if the cover of the pot fits close, it seldom signifies whether the plate is laid on or not, yet, if by accident the cover was not to fit close, the omitting the tin plate would make a very great error. Making the chimney very narrow would not answer the end properly; for, if it was made so small as to make the vessel sufficiently close when the water boiled gently, it would not leave sufficient passage for the escape of the steam when the water boiled fast.

Another way of adjusting the boiling point is, to try it in a vessel of the same kind as the former, only with the water rising a little way, namely from one to three or four inches above the ball, taking care that the boiling point shall rise very little above the cover, as in the former method. In this method there is no need to cover

the

the chimney with the tin plate; and there is less need to make the cover fit close, only it must be observed, that the closer the cover fits, the less the operator will be incommoded by the steam. The height of the barometer at which the boiling point should be adjusted, when this method is used, is  $29\frac{1}{2}$  inches, or three-tenths of an inch less than when the former method is used.

It will be convenient to have two or three pots of different depths; for if a short thermometer is to be adjusted in the same pot which is used for a long one, it will require a great depth of water, which, besides taking up more time before it boils, makes the observation rather less accurate, as the heat seems to be less regular when the depth of water in the pot is very great, than when it is less.

Perhaps some persons, for the sake of heating the water more expeditiously, may be inclined to use an apparatus of such kind that the fire shall be applied to a considerable part of the sides of the pot as well as to the bottom; we would, however, caution them against any thing of that kind, as the observations are considerably less regular than when little more than the bottom of the pot is heated. If the pot is heated over a chafing-dish or common fire, we apprehend that there can seldom be any danger of too much of the sides being heated;

but if the operator should be apprehensive that there is, it is easily prevented by fastening an iron ring an inch or two broad round the pot near the bottom. This precaution is equally necessary when the thermometer is adjusted in steam, especially when there is not much water in the pot.

The greatest inconvenience of this method of adjusting the boiling point is the trouble of keeping a proper depth of water in the pot, as to do this it is necessary first to find the height of the boiling point coarsely by trying it in an open vessel, and then to put such a quantity of water into the pot that it shall rise from one to three or four inches above the ball, when the thermometer is placed at such a depth within the pot that the boiling point shall rise very little above the cover. The operator must be very careful that the quantity of water in the pot be not so small as not entirely to cover the ball.

A third way of adjusting the boiling point is, to wrap several folds of linen rags or flannel round the tube of the thermometer, and to try it in an open vessel, taking care to pour boiling water on the rags, in order to keep the quicksilver in the tube as nearly of the heat of boiling water as possible. The best way is to pour boiling water on the rags three or four times, waiting a few seconds between each time, and to wait some seconds after the last

time of pouring on water before the boiling point is marked, in order that the water may recover its full strength of boiling, which is in good measure checked by pouring on the boiling water.

In this method the boiling point should be adjusted when the barometer is at 29.8 inches, that is, the same as when the first method is used; the water should boil fast, and the thermometer should be held upright, with its ball two or three inches under water, and in that part of the vessel where the current of water ascends<sup>(m)</sup>.

Whichever of these methods of adjusting the boiling point is used, it is not necessary to wait till the barometer is at the proper height, provided the operator will take care to correct the observed height according to the following table.

(m) In a vessel of boiling water one may almost always perceive the current of water to ascend on one side of the vessel, and to descend on the other.

Height of the barometer when the boiling point is adjusted according to,		Correction in thousandths of the interval between 32° and 212°.	Height of the barometer when the boiling point is adjusted according to,		Correction in thousandths of the interval between 32° and 212°.
1st or 3d method.	2d method.		1st or 3d method.	2d method.	
	30.64	10	29.69	29.39	1
	53	9		58	2
30.71	41	8	47	17	3
59	29	7	36	06	4
48	18	6	25	28.95	5
37	07	5	14	84	6
25	29.95	4	03	73	7
14	84	3	28.92	62	8
03	73	2	81	51	9
29.91	61	1	70	—	10
80	50	0	59	—	11

To make use of this table, seek the height which the barometer is found to stand at in the left-hand column, if the boiling point is adjusted either in the first or third method, and in the second column if it is adjusted in the second method; the corresponding number in the third column shews how much the point of 212° must be placed above or below the observed point, expressed in thousandth parts of the interval between the boiling and freezing point: for example, suppose the boiling point

is

is adjusted in steam when the barometer is at 29 inches, and that the interval between the boiling and freezing points is 11 inches; the nearest number to 29 in the left-hand column is 29.03, and the corresponding number in the table is 7 higher, and therefore the mark of  $212^{\circ}$  must be placed higher than the observed point by  $\frac{7}{1000}$  of the interval between boiling and freezing, that is, by  $\frac{11 \times 7}{1000}$ , or .077 of an inch.

This method of correcting the boiling point is not strictly just, unless the tube is of an equal bore in all its parts; but the tube is very seldom so much unequal as to cause any sensible error, where the whole correction is so small. The trouble of making the correction will be abridged by making a diagonal scale such as is represented in fig. 5.

It is not very material what kind of water is used for adjusting the boiling point, so that it is not at all salt; only, if any kind of hard water is used, it is better that it should be kept boiling for at least ten minutes before it is used. But we would advise all those desirous of adjusting thermometers in the most accurate manner for nice experiments, to employ rain or distilled water, and to perform the operation in the first mentioned manner, that is, in steam.

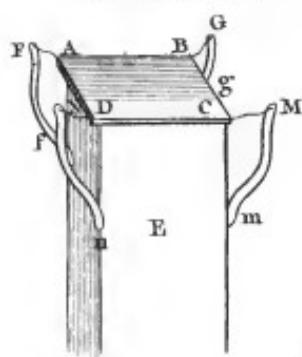
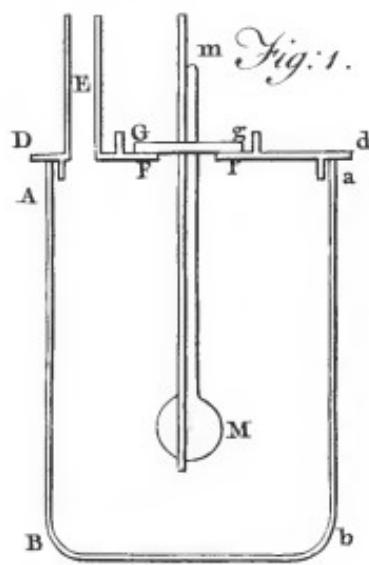
*On the freezing point.*

In adjusting the freezing as well as the boiling point, the quicksilver in the tube ought to be kept of the same heat as that in the ball. In the generality of thermometers, indeed, the distance of the freezing point from the ball is so small, that the greatest error which can arise from neglecting this precaution is not very considerable, unless the weather is warmer than usual; but as the freezing point is frequently placed at a considerable distance from the ball, the operator should always be careful either to pile the pounded ice to such a height above the ball, that the error, which can arise from the quicksilver in the remaining part of the tube not being heated equally with that in the ball, shall be very small; or he must correct the observed point, upon that account, according to the following table:

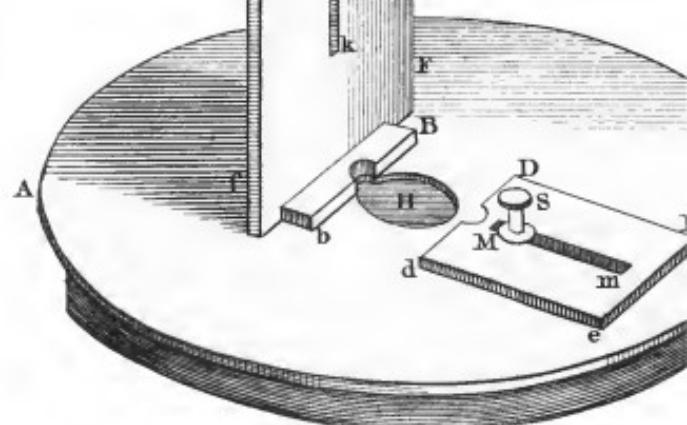
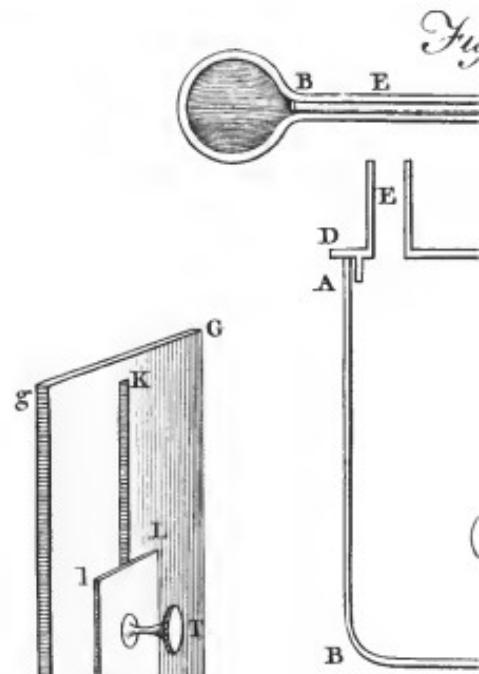
Heat of the air.	Correction.
42°	.00087
52	.00174
62	.00261
72	.00348
82	.00435

The





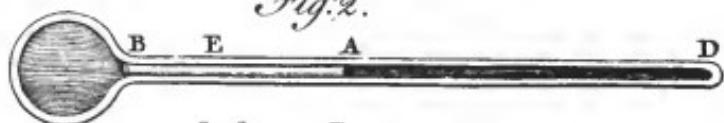
*Fig. 3.*



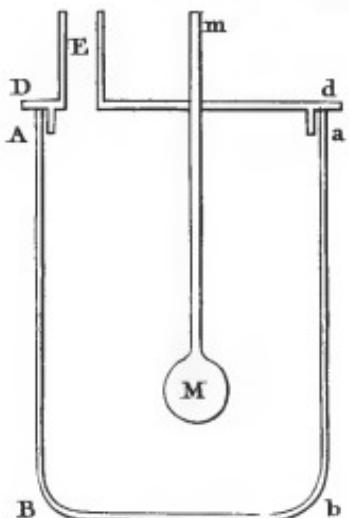
*Fig. 6.*



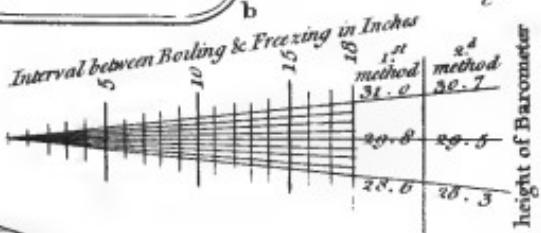
*Fig. 2.*



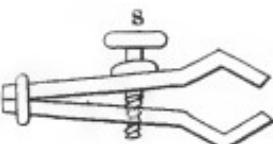
*Fig. 4.*



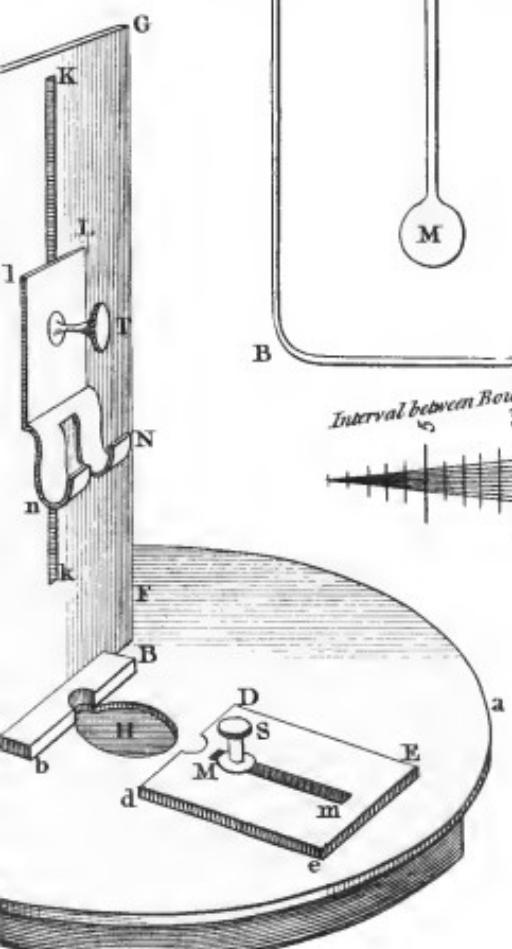
*Fig. 5.*



*Fig. 7.*



*Fig. 6.*



The first column of this table is the heat of the air, and the second is the correction expressed in 1000th parts of the distance between the freezing point and the surface of the ice: for example, if the freezing point stands seven inches above the surface of the ice, and the heat of the room is 62, the point of  $32^{\circ}$  should be placed  $7 \times .00261$ , or .018 of an inch lower than the observed point. This correction also would be made more easy by the help of a diagonal scale, similar to that proposed for the boiling point.

*On the precautions necessary to be observed in making observations with thermometers.*

In trying the heat of liquors care should be taken that the quicksilver in the tube of the thermometer be heated to the same degree as that in the ball; or, if this cannot be done conveniently, the observed heat should be corrected on that account: but for this we refer to the former part, p. 835.

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